

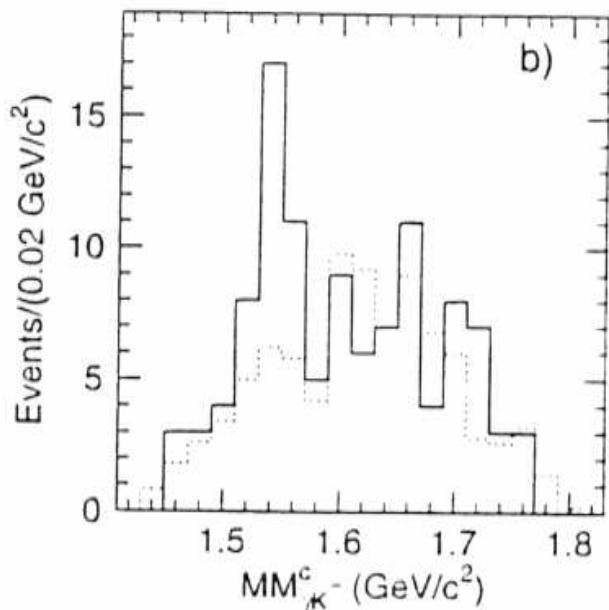
**Pentaquark Experiments  
with  
Hadron Beams**

**J. R. Comfort**

*Arizona State University*

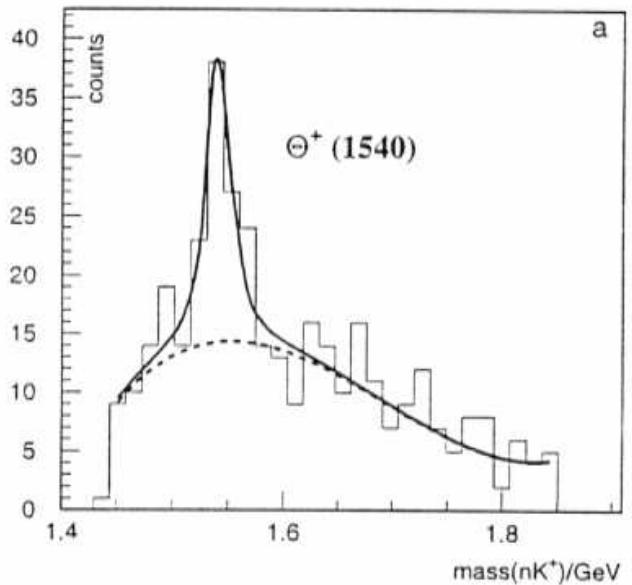
## Spring8

$$\begin{aligned}\gamma n &\rightarrow K^+ K^- n \\ &\rightarrow (n K^+) K^-\end{aligned}$$



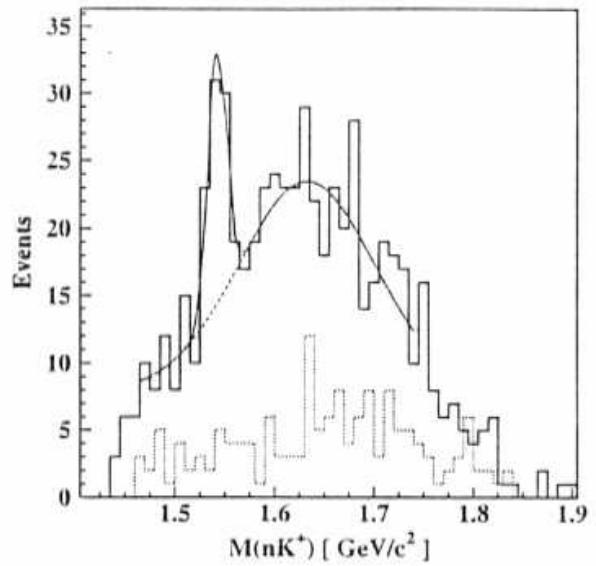
## Bonn/ELSA

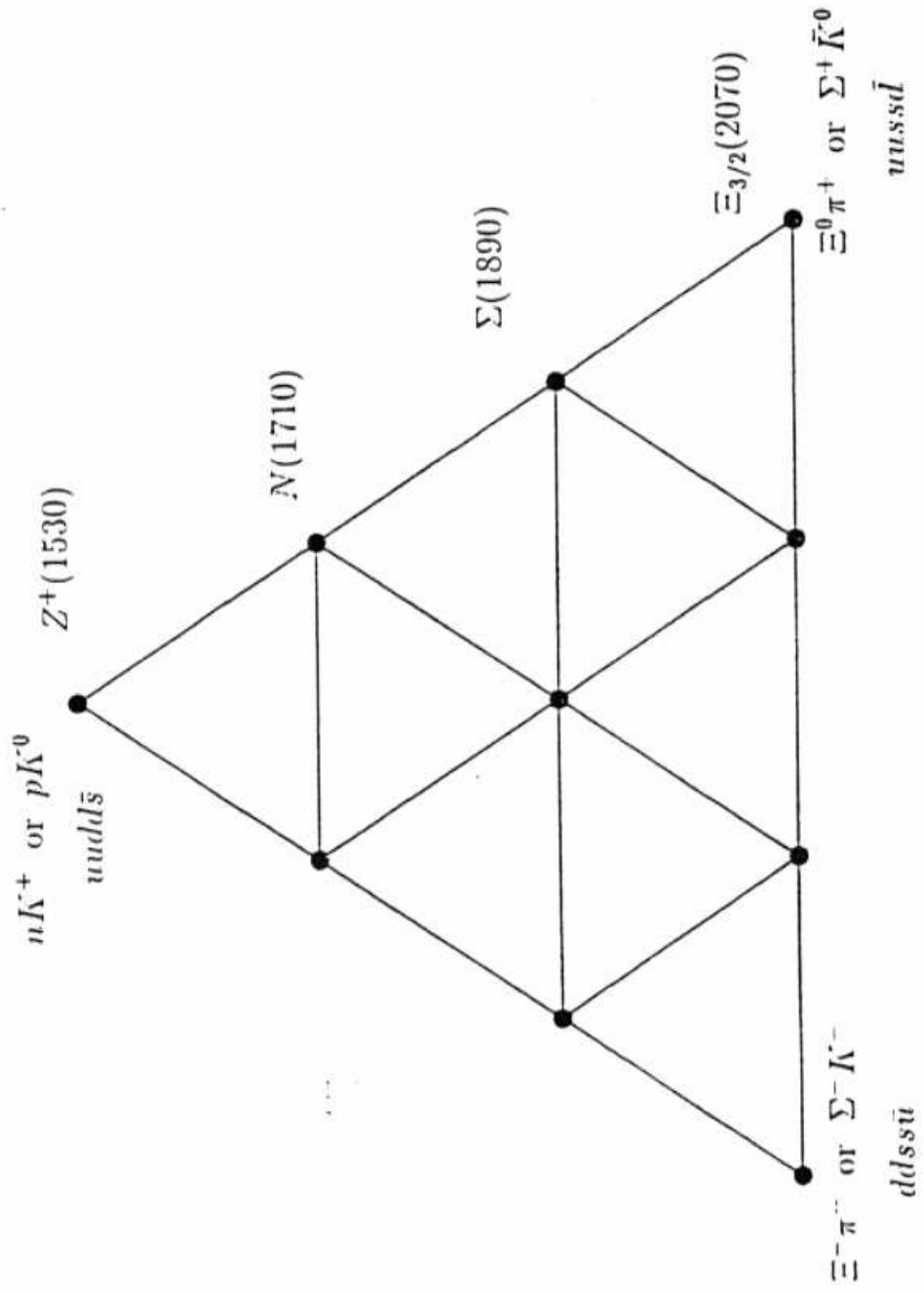
$$\begin{aligned}\gamma p &\rightarrow K^+ K_S^0 n \\ &\rightarrow (n K^+) K_s^0\end{aligned}$$



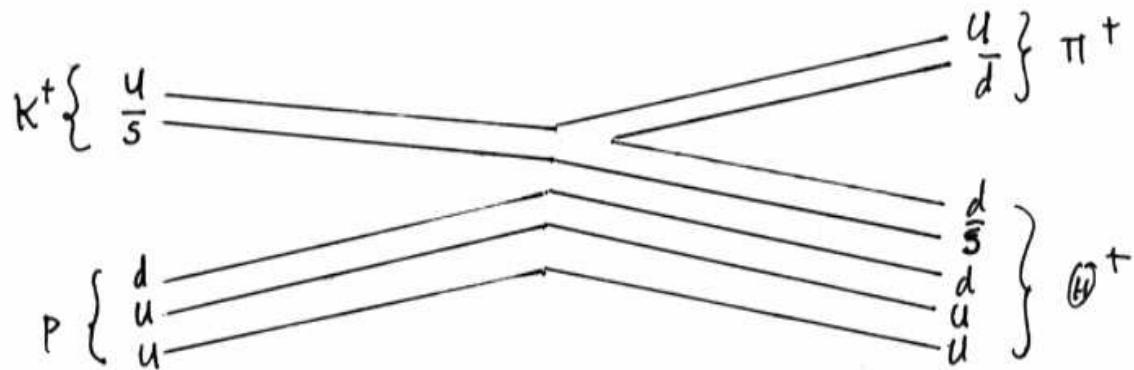
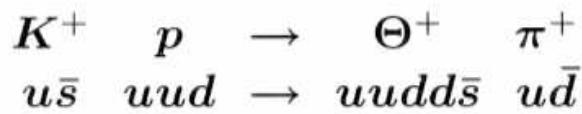
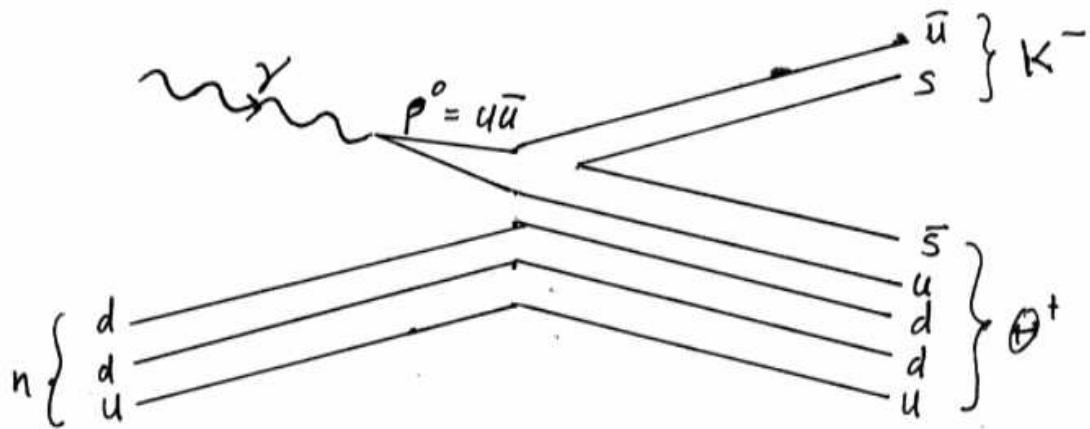
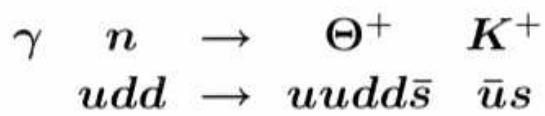
## JLab

$$\begin{aligned}\gamma d &\rightarrow K^+ K^- n p \\ &\rightarrow (n K^+) K^- p\end{aligned}$$





## $\Theta^+$ Production



# Constructing $\Theta^+$ from Quarks

$$\begin{aligned} K^- + p &= \bar{u}s + uud \\ &= uu\bar{u}ds \\ &= uudd\bar{s} + \bar{u} \bar{d} s s \\ &= uudd\bar{s} + \bar{u} s + \bar{d} s \\ &= \Theta^+ + K^- + \overline{K^0} \end{aligned}$$

# $\pi$ & $K$ Experiments for Pentaquarks

## $K^+n \rightarrow \Theta^+$ Excitation Function

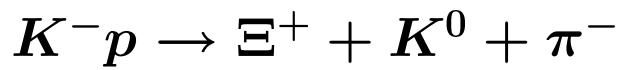
- Resonant  $p_K = 442$  MeV/c, in  $nK$  CM.
- Look for  $\Theta^+ \rightarrow K^+n \rightarrow \pi^+\pi^0n$   
or  $\rightarrow K^0p \rightarrow \pi^+\pi^-p$ .
- Sufficient flux at C2 port.
- Neutron target normally means a deuterium target.

## $K^+p \rightarrow \Theta^+ + \pi^+$

- Threshold  $p_K = 735$  MeV/c.
- Look for  $K^+n\pi^+ \rightarrow \pi^+\pi^0n\pi^+$   
or  $K^0p\pi^+ \rightarrow \pi^+\pi^-p\pi^+$ .
- C2 Port probably OK.
- Matches better to D Line.

$$M(\Theta^+) = 1540 \text{ MeV}$$

Mass of  $pK^+\pi^0 = 1567$  MeV  
[ Threshold  $p_{K^+} = 510$  MeV/c ]



- Threshold  $p_K = 1930$  MeV/c.
- Look for  $\Xi^+ \rightarrow \Xi^0\pi^+ \rightarrow \Lambda\pi^0 \rightarrow p\pi^-\pi^0\pi^+$   
or  $\Sigma^+\bar{K}^0 \rightarrow p\pi^0\pi^+\pi^-$   
with  $K^0 \rightarrow \pi^+\pi^-$
- Near the limit of the D Line.



- Threshold  $p_K = 2860$  MeV/c.
- Look for  $\Xi^{--} \rightarrow \Xi^-\pi^- \rightarrow \Lambda\pi^- \rightarrow p\pi^-\pi^-$   
with  $K^+ \rightarrow \pi^+\pi^0$
- Would need a beam-line upgrade.

$$M(\Xi^+) = M(\Xi^{--}) = 2070 \text{ MeV.}$$

## Reactions and Threshold Beam Momenta

| Reaction                                       | Momentum (MeV/c) |
|--|------------------|
| $K^+ n \rightarrow \Theta^+$                   | 442              |
| $K^+ p \rightarrow \Theta^+ \pi^+$             | 735              |
| $K^- n \rightarrow \Theta^+ 2K^-$              | 2570             |
| $K^- p \rightarrow \Theta^+ K^- \bar{K}^0$     | 2570             |
| $\pi^+ n \rightarrow \Theta^+ \bar{K}^0$       | 1700             |
| $\pi^+ p \rightarrow \Theta^+ \bar{K}^0 \pi^+$ | 2010             |
| $\pi^- n \rightarrow \Theta^+ K^- \pi^-$       | 2010             |
| $\pi^- p \rightarrow \Theta^+ K^-$             | 1700             |
| <br>   |                  |
| $K^- n \rightarrow \Xi^+ K^0 2\pi^-$           | 3675             |
| $K^- p \rightarrow \Xi^+ K^0 \pi^-$            | 1930             |
| $K^+ n \rightarrow \Xi^+ 3K^0$                 | 6110             |
| $K^+ p \rightarrow \Xi^+ 2K^0 K^+$             | 6110             |
| $\pi^+ n \rightarrow \Xi^+ 2K^0$               | 4500             |
| $\pi^+ p \rightarrow \Xi^+ K^+ K^0$            | 4500             |
| $\pi^- n \rightarrow \Xi^+ 2K^0 + 2\pi^-$      | 5460             |
| $\pi^- p \rightarrow \Xi^+ 2K^0 \pi^-$         | 4960             |
| <br>   |                  |
| $K^- n \rightarrow \Xi^{--} K^+$               | 2860             |
| $K^- p \rightarrow \Xi^{--} K^+ \pi^+$         | 3300             |
| $K^+ n \rightarrow \Xi^{--} 3K^+$              | 6110             |
| $K^+ p \rightarrow \Xi^{--} 3K^+ \pi^+$        | 6660             |
| $\pi^- n \rightarrow \Xi^{--} K^+ K^0$         | 4500             |
| $\pi^- p \rightarrow \Xi^{--} 2K^+$            | 4500             |
| $\pi^+ n \rightarrow \Xi^{--} 2K^+ \pi^+$      | 4500             |
| $\pi^+ p \rightarrow \Xi^{--} 2K^+ 2\pi^+$     | 5465             |

# Single-Arm Experiment for $\Theta^+$

## Suggested Experiments

- $K^+p \rightarrow \Theta^+\pi^+$  and  $K^+d \rightarrow \Theta^+p$
- $p_K \sim 1 \text{ GeV}/c$        $\Delta p/p \sim 0.7\%$
- $\text{LH}_2/\text{LD}_2$  Targets
- Detect  $\pi^+$  in Moby Dick spectrometer.
- A peak for  $\Theta^+$  must follow kinematics.
- $\Delta L = 0$  and 1, respectively.

## Comments

- Kinematics gives  $T_{\pi^+} = 0$  to 250 MeV.
- $\sigma_{\text{inelastic}} \sim 5 \text{ mb.}$
- Many open channels with one or more  $\pi^+$ .

## Strengths for $k^+ p \rightarrow \Theta^+ \pi^+$

### Decays

$$\Theta^+ \rightarrow \begin{cases} K^+ + n & 50\% \\ K^0 + p & 50\% \end{cases}$$

$$K^+ \rightarrow \begin{cases} \pi^+ + \pi^0 & 21\% \\ \mu^+ + \nu_\mu & 63\% \end{cases}$$

$$K^0 \rightarrow 50\% \ K_S^0 \quad 50\% \ K_L^0$$

$$K_S^0 \rightarrow \begin{cases} \pi^+ + \pi^- & 69\% \\ \pi^0 + \pi^0 & 31\% \end{cases}$$

### Strengths

$$K^+ p \rightarrow \begin{cases} \pi^+ + \pi^+ \pi^0 & + n & 10.5\% \\ \pi^+ + \mu^+ \nu_\mu & + n & 31.5\% \\ \pi^+ + \pi^+ \pi^- & + p & 17.2\% \\ \pi^+ + \pi^0 \pi^0 & + p & 7.8\% \\ \\ \pi^+ + (K^+ n) & & 8.0\% \\ \pi^+ + (K_L^0 p) & & 25.0\% \end{cases}$$

# $K^+ p$ INTERACTIONS IN THE RANGE 0.9-1.5 $GeV/c$ AND ELASTIC SCATTERING PHASE SHIFT ANALYSIS

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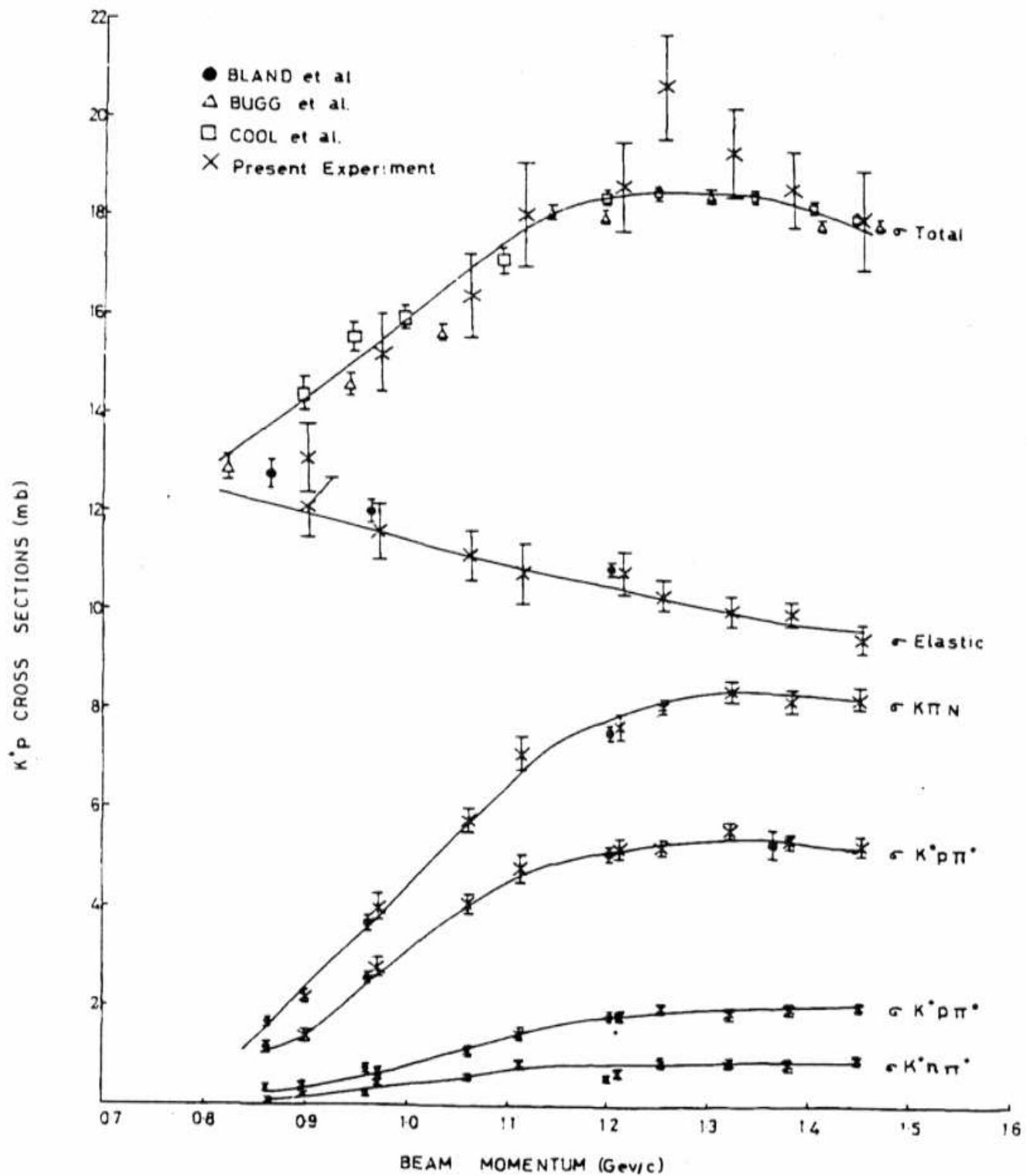
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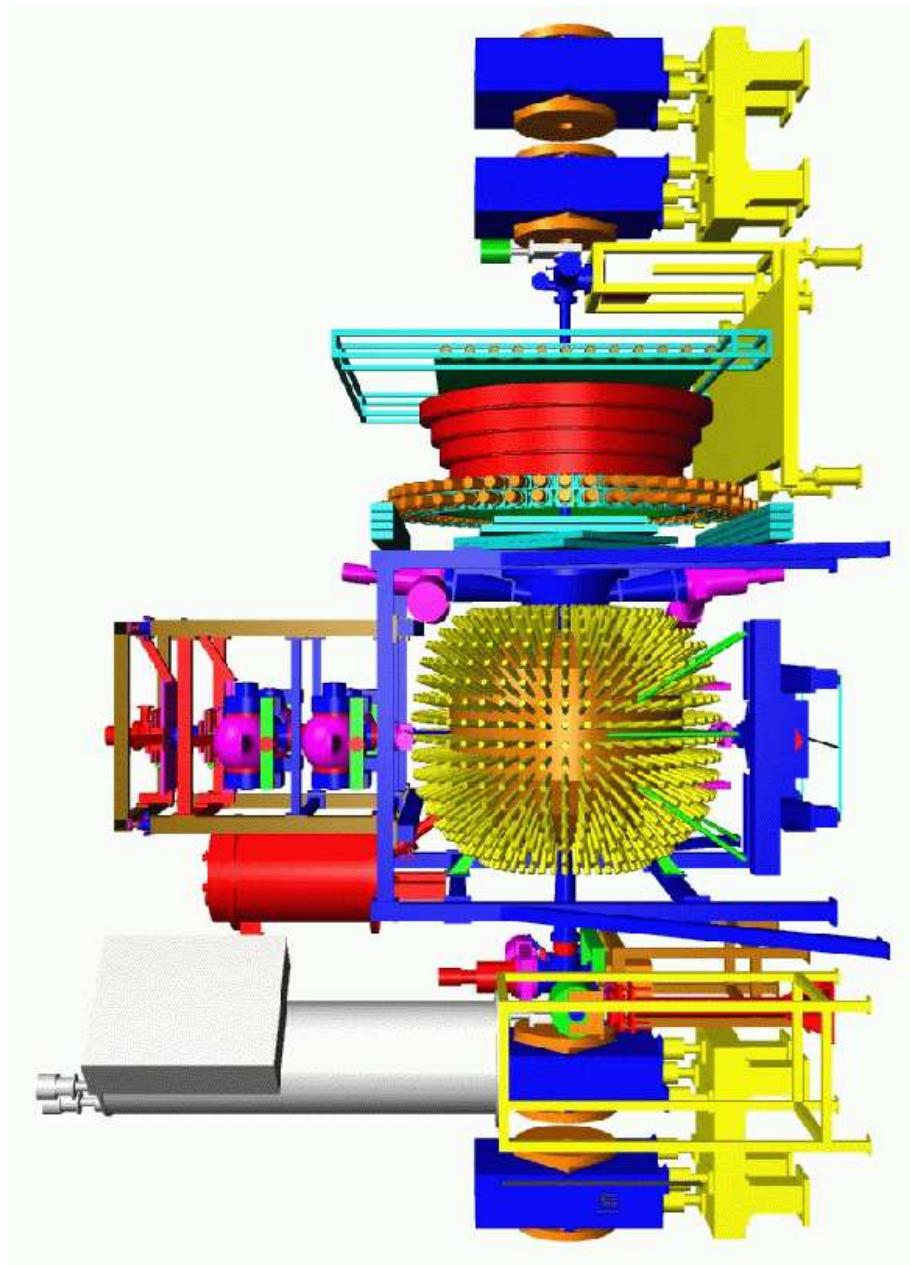
Received 3 February 1970  
(Revised 20 March 1970)

## 1. INTRODUCTION

Interest in  $K^+$  nucleon interactions in the momentum region 0.9-1.5  $GeV/c$  was stimulated by the discovery of peaks in the total  $I = 1$  and  $I = 0$  cross sections in the  $K^+ p$  and  $K^+ d$  measurements of Cool et al. [1]. The results of Cool et al. were confirmed by measurements of Bugg et al. [2]. If these peaks are due to the formation of  $s$ -channel resonances, then the intermediate  $s$ -channel states have strangeness +1 and baryon number +1 ( $Z^*$ 's). The simplest SU(3) assignments of such states are an antidecuplet ( $I = 0$ ) and 27-plet ( $I = 1$ ). These multiplets cannot be formed in the simple three-quark model of baryons. In addition, there is no strong evidence for the existence of other particles which require such multiplets [3-5].



# WASA Facility



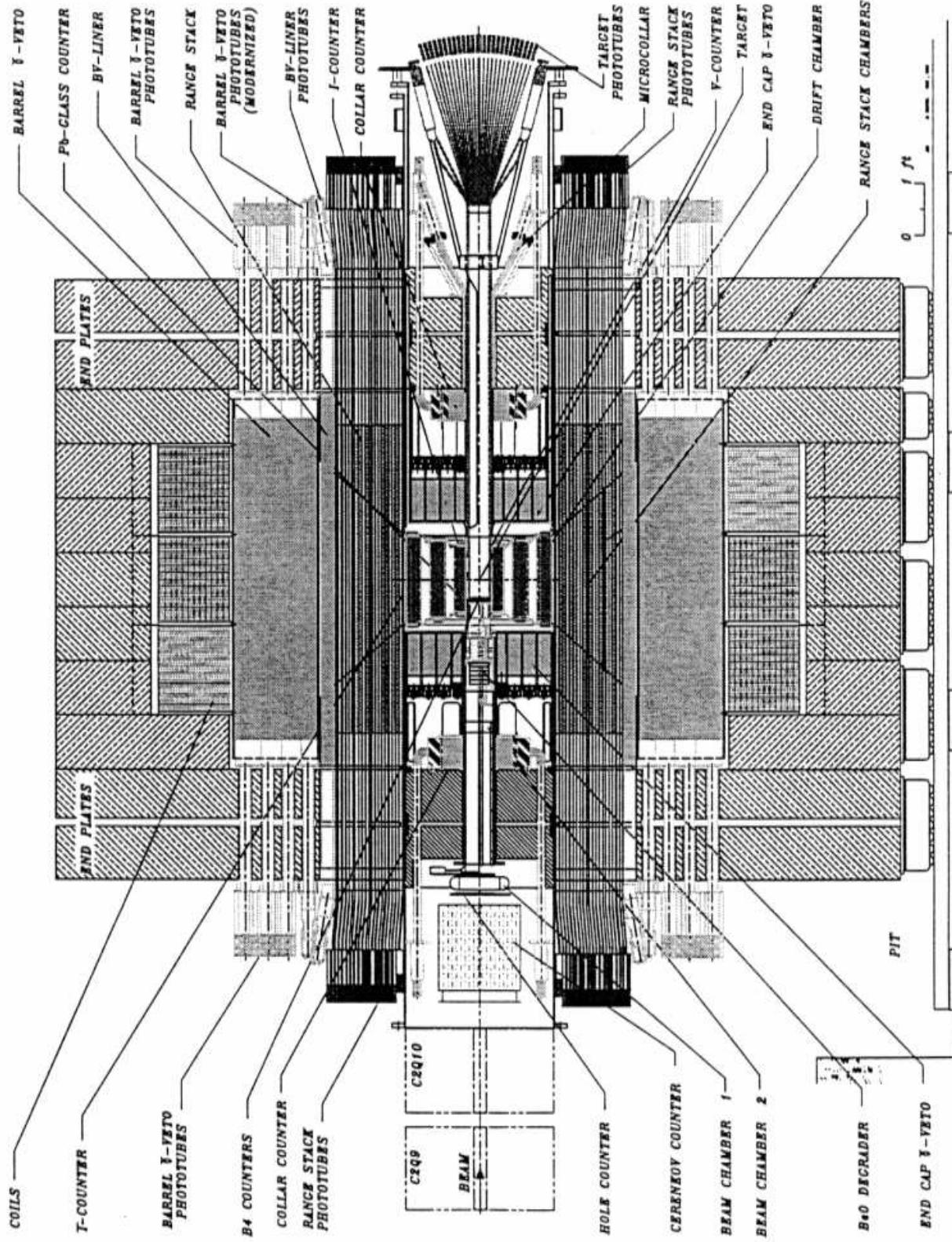


Figure 5: The E949 detector.

Director's Office



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September 17, 2003

Dr. Curt Ekstrom  
The Swedborg Laboratory  
Uppsala University  
Thunbergvagen 5A  
S-75121 Uppsala  
SWEDEN

Dear Dr. Ekstrom:

I have learned from Joe Comfort of the possibility that the WASA detector is likely to be available for use in experiments at other laboratories within the next 2-3 years.

In addition to the E927 experiment, I am aware of activities in the Nuclear Physics community to define a program in hadron spectroscopy using pions and kaons up to and beyond 2 GeV. BNL has, arguably, the best facilities worldwide for the goals of such a program in the near-term and the discussion has focused on establishing the program at the AGS. BNL would welcome proposals to carry out such a program. Again, the WASA detector has the right combination of features that to allow the experiments to succeed.

Sincerely,

Thomas B.W. Kirk  
Associate Laboratory Director  
High Energy and Nuclear Physics

Cc: J. Comfort

## Summary and Conclusions

- Pentaquarks are one of the most exciting developments in subatomic physics.
- This topic alone can justify an extended, systematic baryon spectroscopy program.
- Pentaquarks are being pursued vigorously at many laboratories, albeit with probes that are less than ideal.
- Pion and Kaon beams are best for future studies.
- BNL has the best  $\pi$  and  $K$  beams, now and for many more years.
- A suitable detector is a challenge, but the E787/E949 detector might be adaptable.
- Funding is a slow process. Expressions of community interest should begin now.